

Laser Zaps Communication Bottleneck

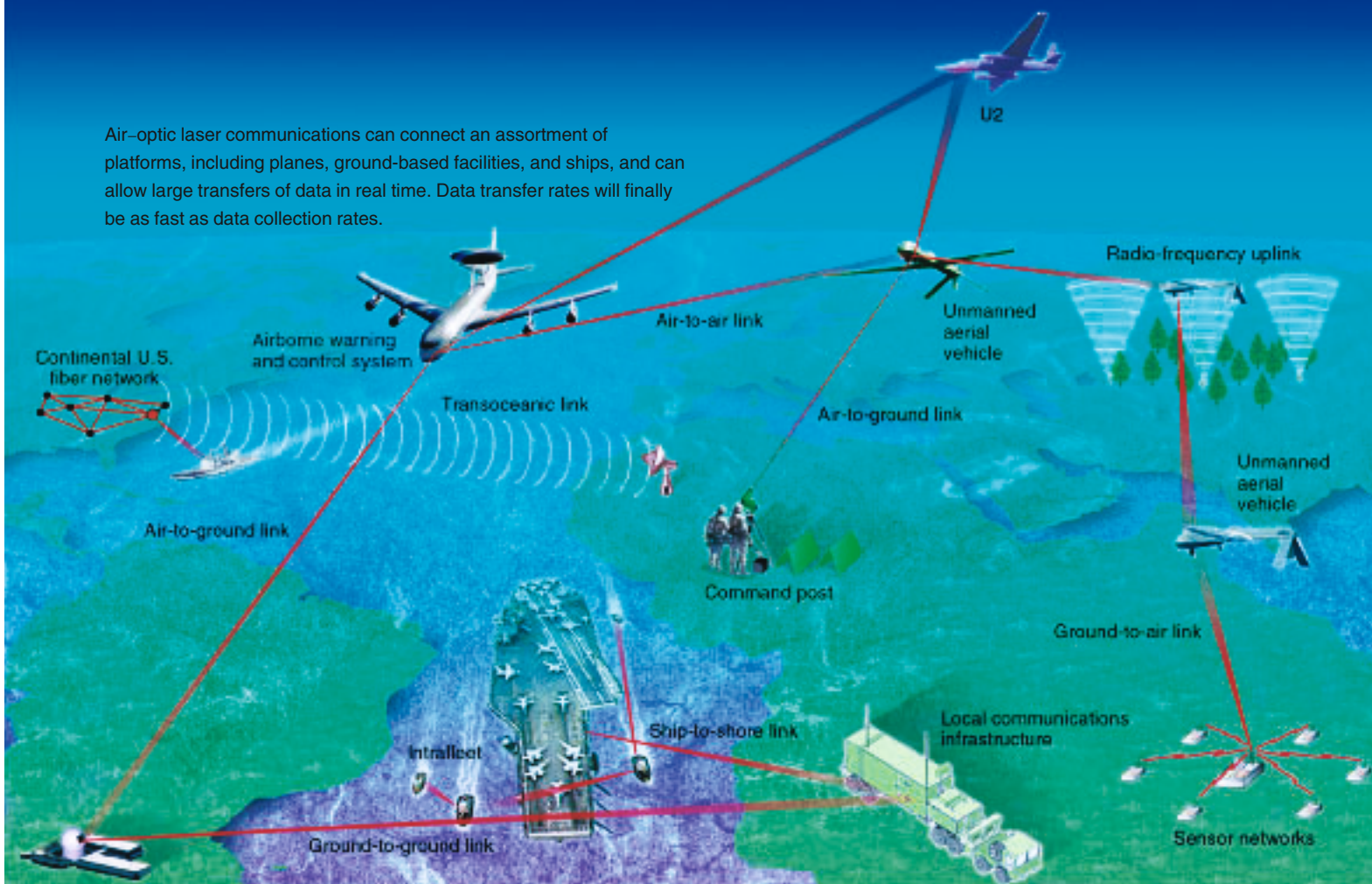
BACK in February, the first laser communication link between Lawrence Livermore and the top of the 915-meter-high Mount Diablo, 28 kilometers away, transmitted data at 2.5 gigabits per second on a single laser channel, a rate comparable to 1,600 conventional T1 (local area network) data lines, 400 channels of television, or 40,000 simultaneous phone calls. "That event was one of the longest terrestrial high-capacity air-optics links ever," says Tony Ruggiero, principal investigator for the project.

Even though there's the ever-present beeping of cell phones, buzzing of pagers, and notices popping up that you've got mail, users still demand better, faster communications. The demand is especially high from the military, whose highly sensitive, remote, sensor-based intelligence, surveillance, and reconnaissance (ISR) systems collect massive quantities of data.

Tremendous improvements have been made on data collection capabilities. Now the challenge is delivering data for timely evaluation and action. "Advanced sensors can collect data at rates of up to a gigabit per second," notes Ruggiero. "But the fastest that the data can be transmitted is currently 270 megabits per second using state-of-the-art radio frequency links." For most ISR applications, data from several types of sensors must be aggregated to be useful, driving the total data collection rate into the tens of gigabits per second and creating a massive bottleneck.

Since the February test, Ruggiero's project, the Secure Air-Optic Transport and Routing Network (SATRN), has closed the link between the Laboratory and Mount Diablo at 10 gigabits per second using four 2.5-gigabit-per-second channels running at slightly different wavelengths. The team

Air-optic laser communications can connect an assortment of platforms, including planes, ground-based facilities, and ships, and can allow large transfers of data in real time. Data transfer rates will finally be as fast as data collection rates.



collected extensive performance data under a variety of atmospheric and weather conditions. Soon, Ruggiero expects to be delivering data via a laser beam at the rate of 100 gigabits per second.

The success of the SATRN project may finally give the U.S. military the means to eliminate the bottlenecks that have hindered information transfers to date. Data will also be able to move quickly and securely among various kinds of platforms—between a moving plane and ship, for example, or from a plane to a ground-based facility.

Reducing the Response Timeline

“The bad guys feed off latency—the delay between gathering intelligence and being able to use it,” says Ken Israel, former director of the Defense Airborne Reconnaissance Office.

Latency is a challenge when, for example, ISR sensors onboard an unmanned aerial vehicle (UAV) detect enemy activity. As shown in the figure below, the chain of events that follows the detection is to reorient sensors to gain additional information and then use high-resolution imagery to verify the activity, target it, and finally destroy it. Reducing this sensor-to-shooter timeline is a primary goal of the SATRN project.

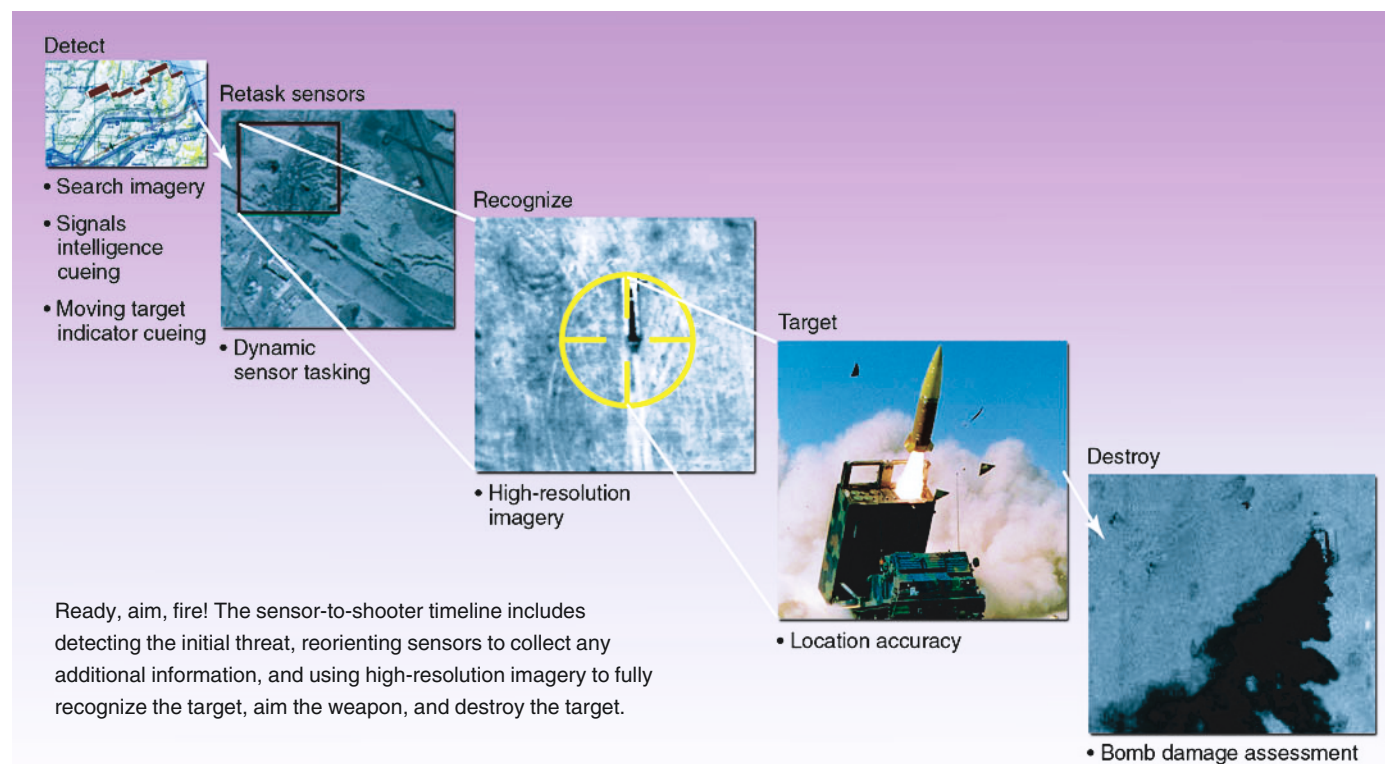
Today, about 30 minutes of image data from the UAV would take 83 days to transmit over a 56-kilobit ISDN (digital phone) line, 3 days over a T1 line, or 15 minutes over the best transfer technology available. With a 1-gigabit-per-second laser communication line, data transfer would occur in real time. Verification, targeting, and destruction would follow almost immediately.

“With data transfers at 40 to 100 gigabits per second, multiple sensors could be combined in a single platform,” says Ruggiero. “A UAV could carry synthetic aperture radar, signal intelligence, and video, and all of them could be transmitting information at once to the decision makers in command.”

New Technologies Make It Work

Laser communication is already in use but only to transmit information very short distances, typically from 100 to 500 meters and usually between buildings. Extending laser communication over longer distances and between mobile platforms has been hampered by the effects of the atmosphere on the laser beam.

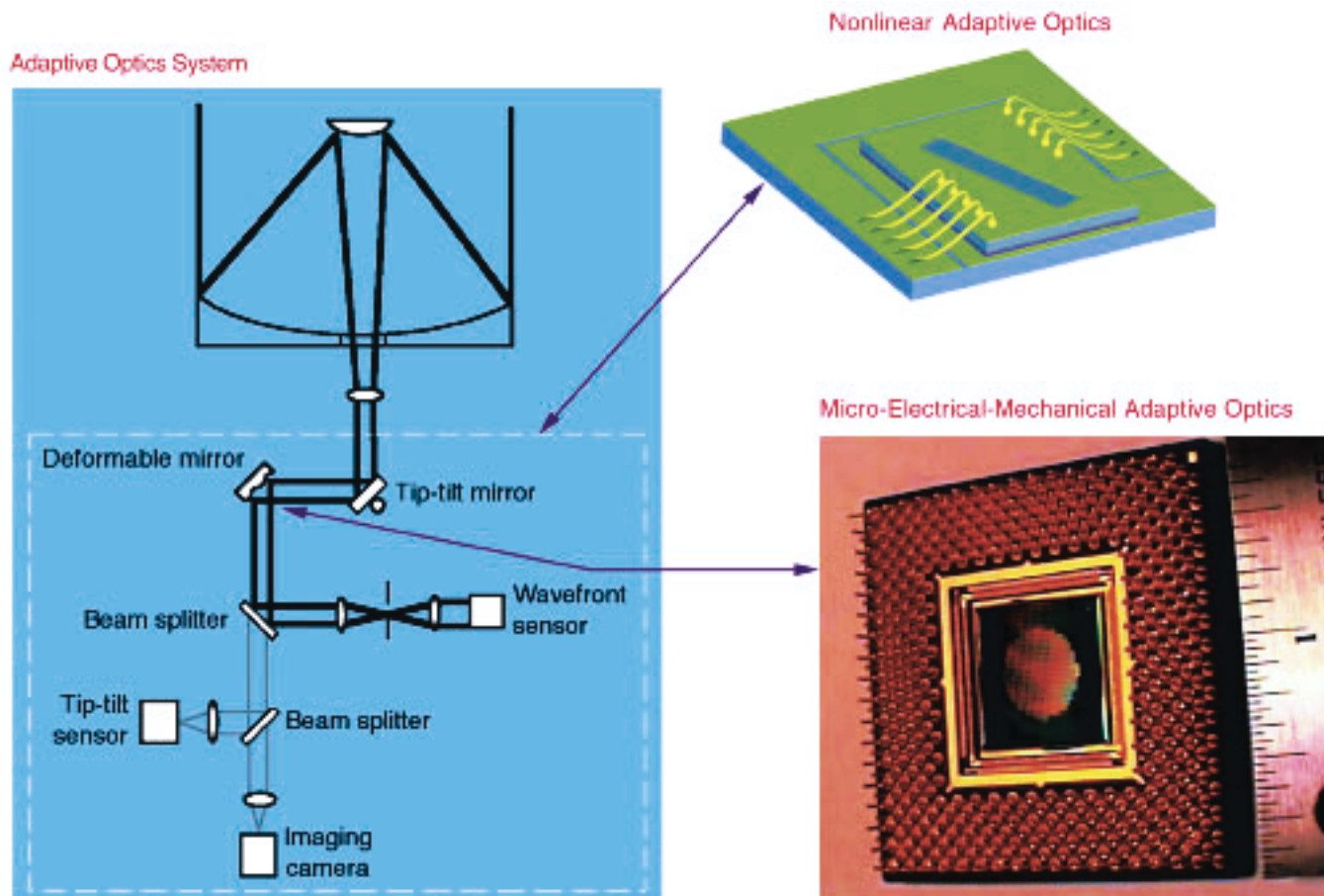
The atmosphere is composed of random pockets of slightly varying temperature that destroy the spatial properties of an



electromagnetic beam and cause the beam's intensity to fluctuate at the receiver. This is a much greater problem for the shorter wavelengths used in laser links than it is for radio and microwaves. Atmospheric attenuation—the interaction of the laser beam with gases and particulate matter in the air—is another problem that causes an overall reduction in the detected power level of the beam. At the same time, atmospheric turbulence causes the beam to break up, spread, and wander, so that its power fluctuates. Livermore's SATRN team is developing several innovative technologies to cut through the atmosphere, minimize beam fading, and amplify the power of the beam.

Cutting through the atmosphere to maximize transmitter and receiver beam coupling can be done most efficiently with adaptive optics. Livermore-developed adaptive optics systems

have already proved their mettle in astronomical observatories, where they mitigate the atmospheric disturbances that prevent astronomers from having a clear view of stars. (See *S&TR*, July/August 1999, pp. 12–19, and June 2002, pp. 12–19.) For SATRN, the team is producing two versions of adaptive optics to enhance laser communications. One is based on micro-electrical-mechanical systems and builds on adaptive optics technology that Livermore has been working on for almost a decade. The other is an entirely new methodology based on nonlinear optics in fibers and semiconductor systems. Still in the research and development phase, these approaches show promise of exceeding the performance of current adaptive optics receiver systems.



Adaptive optics systems in use today in astronomical observatories have deformable mirrors that move extremely quickly to compensate for atmospheric disturbances. Nonlinear adaptive optics, a revolutionary new technology, uses fiber optics and semiconductor chip technology to make real-time corrections to the spatial profile of a laser beam.

Minimizing beam fading caused by beam wander and obscurations such as birds in the laser path requires a process known as forward error correction. Conventional error correction methods do not work for laser communications because of the high data rate and relatively long duration of the atmospheric fades. The SATRN team is collaborating with industry to develop new error correction techniques specifically for air-optic communications.

Lastly, to overcome path losses due to poor air quality and fog, new high-power fiber amplifier technologies are based on photonic crystal fiber technologies. For this work, Livermore is collaborating with researchers at the University of Bath in the United Kingdom, where photonic crystal fibers were invented. The new technology may provide 10 times the power of current commercial amplifiers that are designed for use in wavelength-division-multiplexed communication systems.

Crucial to all of this work is modeling the laser beam both as it propagates normally through the atmosphere and as it propagates with various new technologies. Modeling is helping the team to optimize the design of the optical system and predicting the performance of open-air links under specified atmospheric conditions and ranges. "We will soon integrate the codes to provide an unprecedented capability at Livermore for simulating terrestrial laser communications," notes Ruggiero.

Beaming Up to the Future

The next major experiment for SATRN will be to create a link to airplanes and UAVs in collaboration with the U.S. Navy's Third Fleet and the Naval Postgraduate School in Monterey, California. That effort will take place in 2003.

Work to date on SATRN has been internally funded by Laboratory Directed Research and Development. Beginning next year, the Department of Defense and other government sponsors will fund further development and experimental deployments. SATRN technologies will be integrated into the Tera-Hertz Operational Reachback (THOR) program of the Defense Advanced Research Projects Agency, the primary research and development organization for the Department of Defense. The goal of THOR is to develop high-bandwidth air-to-air, air-to-ground, ground-to-air, and air-to-sea optical links to the tactical warfighter. SATRN will fit right in.

—Katie Walter

Key Words: laser communications link, Secure Air-Optic Transport and Routing Network (SATRN).

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